Coastal Engineering Technical Note

DESIGN GUIDANCE FOR SELECTIVELY PLACED QUARRYSTONE REVETMENT ARMOR LAYERS

PURPOSE. To provide improved guidance for design of revetment armor layers in those circumstances where quarrystones can be selectively placed.

BACKGROUND. Field practice is to place quarrystone armor units to provide the best fit obtainable for particular site conditions. The selective placement of quarrystones, i.e., the selection and placement of armor stones one at a time to achieve the best fit (often called standard placement), is known to provide better stability. Placement methods have previously been discussed in CETN-III-4, "Armor Unit Placement Method Versus Stability Coefficients," which noted in regard to selective placement that, "Specific values of the stability coefficient *KD* have not been developed for the selected placement method because of the variation which may occur from project to project." Therefore, while stability coefficients are provided herein for the design of selectively placed quarrystone armor layers for revetments, individual field offices must determine whether or not that placement method will be obtainable on specific projects. Various factors influencing placement are water clarity, wave climates and currents expected at the project site, equipment used (including whether it will be land-based or water-based), and experience of the equipment operators. Guidelines for selective placement specifications are given in CETN III-59.

LABORATORY TESTS. Laboratory tests were conducted at the U.S. Army Engineer Waterways Experiment Station's Coastal Engineering Research Center in a 2-ft-wide wave flume. Model revetments having slopes of 1:1.5, 1:2, and 1:3 were tested. A foreslope of 1:50 (2 percent) was used in front of the structure. The model revetments were constructed to be "impermeable," with a dense sand core overlaid with filter cloth. Layers of smaller bedding stone were used under the model armor stone. This bedding stone conformed to the present guidance in the *Shore Protection Manual* (1984), i.e., $w_{50}/10$ for a first underlayer and $w_{50}/200$ for a second underlayer.

Tests were conducted for single layers of armor stones. Construction of revetments using single armor layers may result in substantial savings in construction costs. Tests were conducted using model armor stones with a median weight of 0.47 lb, and a range from 0.31 - 0.70 lb ($0.66\ w_{50}$ - $1.49\ w_{50}$). This wider gradation, in comparison to the ± 25 percent w_{50} gradation specified in the *Shore Protection Manual*, (1984) had no adverse effect on stability of the structures.

Both spectral and monochromatic waves were used in the tests. Tests were conducted with waves breaking on the model revetments. A total of 11 model revetments were tested to failure. Failure was defined as the condition where armor stones began to be displaced (at least one armor stone displaced or strong movement, i.e., waves lifting an armor stone completely up and dropping it back into place), i.e., incipient failure. For the structures tested, this was displacement or strong movement of less than 1 percent of the armor stones.

Based on the Hudson equation, stability coefficients at failure (as defined above) ranged from $K_D = 4$, where one or more stones were not as well placed, up to $K_D = 23$, where stones were very well placed. No consistent trend was found in these test results to relate wave period to stability. It was noted that individual stones responded to some wave periods, but not necessarily the longest wave period.

CONSIDERATIONS OF REVETMENT SLOPE. Factors affecting the design decision on structure slope will vary between project sites. The following laboratory observations may be used for guidance:

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a. Steep slopes will use less stone, and the stone may be more easily placed because the reach requirement of the equipment is shorter. The stones used in the model tests tended to stack together tighter on the 1:1.5 slope and, based on the Hudson equation, the model revetments with the 1:1.5 slope tended to have higher stability coefficents than the model revetments with flatter slopes. However, the model revetments constructed with a 1:1.5 slope exhibited slope failure (the entire armor layer tended to slip downward) if the toe of the armor layer was not keyed in well at the bottom. Also, specific test conditions for the 1:1.5 revetment slope produced strong wave-structure interaction, i.e., interaction between incident and reflected waves, which is believed to be dependent on the combination of wave and site variables. Parameters determining wave-structure interaction are not yet well defined, but strong wave-structure interaction only occurred in tests with the steeper slope. As wave-structure interaction may produce the critical condition for structural failure, structures designed for a 1:1.5 slope should be carefully model tested for wave-structure interaction.

b. Flatter slopes, e.g., 1:3, use more stone and placement may be more difficult because the reach requirement of the equipment is longer. In the model tests, the stones did not stack together as tightly and, based on the Hudson equation, the model revetments with the 1:3 slope tended to have lower stability coefficients. However, the armor layer is believed to be less prone to slope failure, was successfully tested with a smaller underlayer stone (i.e., the first underlayer mentioned above was eliminated), and test conditions did not produce the strong wave-structure interaction observed on the 1:1.5 slope (similar tests were conducted for the 1:1.5 and 1:3 structure slopes, with the structure slope as the only variable). As an additional finding, some incident wave periods tended to be damped out by wave reflections from the structure slope, i.e., tests were unable to obtain breaking waves on the structure for specific wave periods. It is possible that a flatter structure slope may significantly reduce wave breaking on the structure.

RECOMMENDATIONS. Based on the present tests, a stability coefficient of $K_D = 4$ is recommended for selectively placed quarrystone armor units used in revetments. This value is believed to be conservative for well-placed quarrystones.

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REFERENCES.

Coastal Engineering Research Center. (1985). "Armor unit placement method versus stability coefficients," Coastal Engineering Technical Note (CETN) III-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Coastal Engineering Research Center. (1995). "Specification guidelines for the placement of quarrystone armor units - lessons learned," Coastal Engineering Technical Note (CETN) III-59, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Shore protection manual. (1984). 4th ed., 2 Vol, U.S. Army Engineer Waterways Experiment Station, U.S. Government Printing Office, Washington, DC.